MILLISECOND PULSAR OBSERVATION AT CRL

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Abstract

We will report the current status of millisecond pulsar timing observation at CRL. Weekly observation of PSR1937+21 using the 34-m antenna at Kashima Space Research Center has been on going since November 1997. Recently we eliminated systematic trends that were apparent in the data, and estimated the pulsar parameters of PSR1937+21. Standard deviation of timing residuals is 2.4 μs for about 3 hours' pulse-integration. The frequency stability of PSR1937+21 is 10^{-13} for an averaging time of one year, which demonstrates the possibility of constructing a pulsar time scale with a system using a small antenna.

INTRODUCTION

Pulsars are thought to be rotating neutron stars radiating radio beams from their oblique magnetic poles. Some pulsars have short pulse periods of millisecond order. These millisecond pulsars are known to keep the extremely stable pulse timings over long periods. The millisecond pulsar PSR1855+09 has a pulse period of 5.4 ms pulse rates, and its fractional frequency stability is about the order of 10^{-15} over 8 years, which is comparable to a cesium atomic clock [1; here after paper I].

From such rotational stability, millisecond pulsars are expected as reference time standards. The tie of pulsar time and atomic time are studied to construct a new stable time scale [2][3][4]. In addition, pulsar timing contributes to the various researches. Pulsar timing depends on the time scale and ephemeris used for the analysis, shown in paper (I), so it is useful for the comparison of some time scales and ephemerides. It also contributes to the reference frame tie. The pulsar's position determined by timing observation is based on the Earth orbit-oriented reference frame, and the position determined by VLBI observation is based on the extragalactic reference frame. By comparing both positions, the different reference frames are combined [5]. Pulsar timing is also expected as the probe for the interstellar medium and gravity in the propagation path.

Communications Research Laboratory (CRL) aims to apply millisecond pulsars to the construction of a new time scale; this entails theoretical research [6], VLBI observation [7], and timing observation. As for the timing observation, we developed an observation system that uses the 34-m antenna at Kashima. Signals from millisecond pulsars are quite weak and the 34-m antenna is not large enough to detect them, so we improved the system's sensitivity by using wide-band observation and longtime integration. The observation system has been completed, and observation of the millisecond pulsar PSR1937+21 has been on going since November of 1997.

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However, we encountered some troubles in that the observed pulse phases showed systematic trends during a day and longer periods, which was reported in PTTI'98 [8]. We have checked our observation system and analysis program carefully, and recently found that these trends are caused by some reasons. The daily trend was caused by insufficient calibration of the Earth rotation, and long-term trend was caused by insufficient correction of observation time and frequency. We solved these problems, and by re-processing the data, obtained a frequency stability of 10^{-13} over 1 year and an estimate of the pulsar's parameters. In this paper, we report an recent progress in millisecond pulsar observation and observation results of PSR1937+21 at the 34-m antenna.

OBSERVATION SYSTEM

Figure 1 shows a block diagram of the observation system. We use the right-handed-circularly-polarized signal in S-band frequency. As for the antenna parameters in S-band, the system noise temperature is 71K, and the efficiency is 65%. An IF signal with 200MHz bandwidth was divided into four bands by the video converter, and each 50MHz bandwidth was divided into 256 channels by the acousto-optic spectrometer (AOS). The frequency resolution is about 200kHz. The 256 channels of each AOS unit were serially transported to the video averaging processor. The transportation trigger clock was synchronized to 1/100 of the pulsar period, giving a time resolution of 16 μs for PSR1937+21. The video averaging processor works as an 8-bit A/D converter and an averaging processor. It can average a maximum of about 17 million pulses for each channel. The averaged signals were recorded at host computer #1. After the observation, dispersion delay corresponding to the observation frequency was calibrated in each channel; then the signals of all channels were combined.

The averaging trigger clock must be synchronized to the observed pulse period. The observed pulse period is not constant because of the Doppler effect, so host computer #2 calculated the predicted period and controlled the synthesizer in real time. The predicted value was calculated by the program TEMPO. TEMPO is the pulsar timing analysis package developed by the Princeton pulsar group [9], which can calculate the predicted period and pulse phase at any observatory. The observation time was obtained from the laboratory clock, which is phase-locked to a hydrogen maser. The averaging start time was measured by the time-interval counter. The time offset of the laboratory clock from UTC was monitored using a GPS receiver. All the oscillators were phase-locked to the hydrogen maser.

OBSERVATION OF PSR1937+21

TIMING RESIDUALS

Regular observation of the millisecond pulsar PSR1937+21 has been on going since November 1997. This pulsar is useful as a system performance check, because it is the brightest millisecond pulsar in the northern sky and has been observed at other stations for a long period of time. The observations are carried out once a week, and 8 hours per day. Figure 2 shows the pulse profile obtained from 50MHz bandwidth signals and 27 minutes of integration.

From such profiles, we determined the peak phases of the pulses, transformed them to the arrival time, compared them with the predicted time of arrivals (TOA), and obtained the residuals. The predicted TOAs were calculated by TEMPO. We adopted DE200 as the ephemeris and UTC as the reference

time scale. We used only the data of AOS #1 for the analysis, because other three units experienced hardware problems during the measurement period. Figure 3 shows the residuals, which is the same as results reported in PTTI'98. Figure 3(b) shows an example in 1 day picked up from Fig. 3(a). Some systematic trends are apparent. There is a drift on most observation days. We determined that the daily drift was caused by insufficient calibration of Earth rotation. The long-term trend was caused by a variety of reasons. Some were due to miscalibration of the observation frequency at the AOS. Others were due to insufficient calibration of the laboratory time offset. We fixed these problems and finally obtained a smooth line, which is shown in Fig. 4.

PARAMETER FITTING

The residuals in Fig. 4 still show a drift, so we carried out a parameter fitting for seven parameters: frequency f, frequency deviation df/dt, Right Ascension RA, Declination Dec, proper motion PRA, Pdec, and parallax px. We used the initial parameters derived from paper I. After the first fitting, the drift in Fig. 4 disappeared and the residuals were distributed without biases (Fig. 5). The standard deviation of the residuals is 6.4 μs for the 27-minute pulse-integration. We changed the initial parameters and did the fitting again; the parameters converged to the same values. Table 1 compares the parameters after fitting with those of paper I. Except for the frequency and its derivative, all values agree with Paper I within each error range. The frequency that is the reciprocal of the period agrees with paper I's value to 11 digits. The frequency derivative agrees to the order of 10^{-17}. A more reliable parallax will be obtained from the long years' observation.

FREQUENCY STABILITY

We estimated the frequency stability by the Allan variance of the residuals after fitting. At first we calculated the representative TOA for each observation day by averaging all TOAs in one day (Fig. 6). They corresponded to the TOAs obtained from the pulses after about 3 hours' integration. The standard deviation was 2.4 μs for the residuals of each day. From these residuals, we calculated the Allan variance for the time intervals of 7, 14, 21, ...,364 day. Figure 7 shows the frequency stability. It seems to be proportional to $1/\tau$, which suggests the white PM system noise is dominant in this region. The stability at one year is about 1×10^{-13}, which is the expected order from our system's performance.

CONCLUSIONS

Continuous observation of PSR1937+21 at Kashima 34-m antenna has been on going since 1997. Timing residuals showed an unusual behavior at first, but the reasons have become clear recently. We solved them and then calculated the pulsar parameters from our data. The fitted parameters are about the same as those of paper I, which means the calculation was carried out properly. After parameter fitting, the residuals are distributed without bias. The standard deviation is 6.4 μs for the residuals obtained from the pulses after 27 minutes' integration, and 2.4 μs for the residuals obtained after about 3 hours' pulse-integration. They are the results obtained from the observation with 50MHz bandwidth, and if 200MHz bandwidth is available, the standard deviation will be about 1 μs. The frequency stability is about 10^{-13} at 1 year. These results demonstrate the possibility of using our system for millisecond pulsar timing observation. We plan to improve the precision of our system

and use it to observe other millisecond pulsars for contributing to the construction of pulsar time scale.

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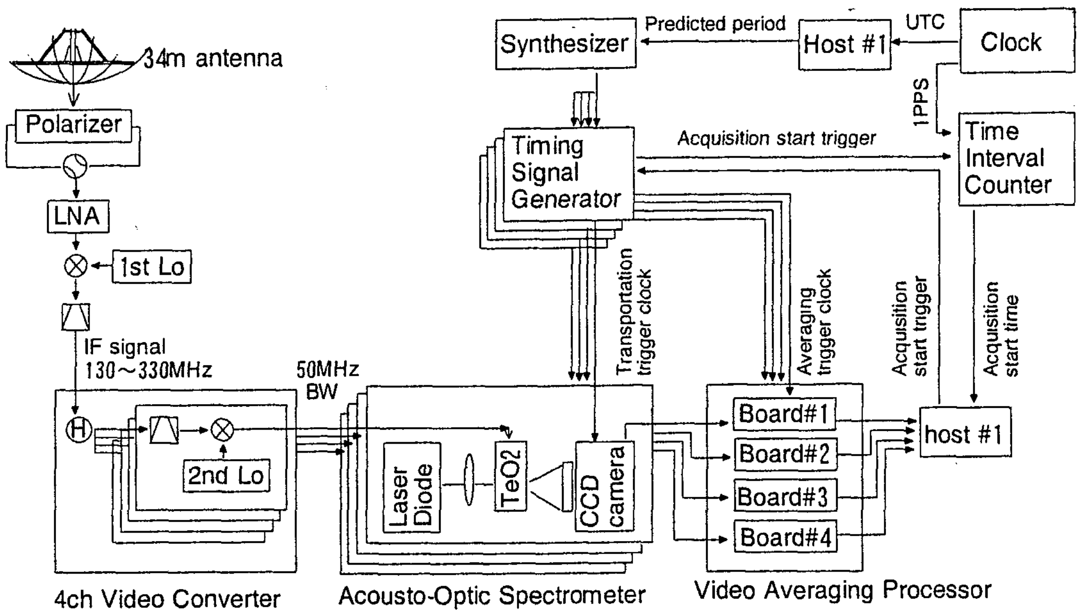
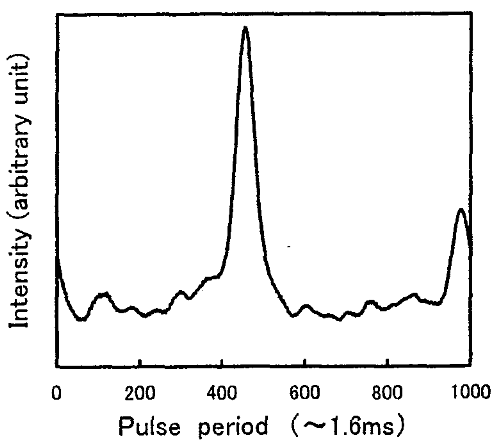


Figure 1: Millisecond pulsar observation system at CRL.

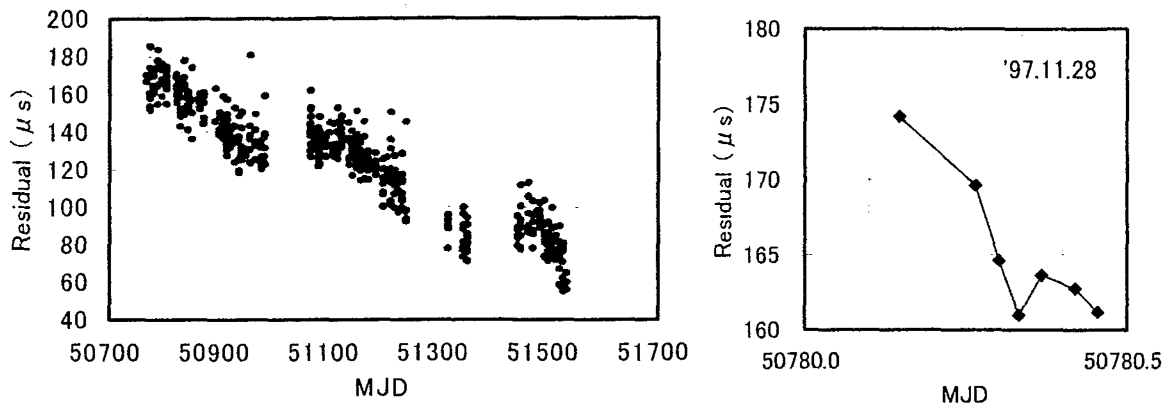


PSR1937+21

Period: P ~ 1.6 ms
dP/dt ~ 1.1×10^{-19}
Flux density: <S> ~ 3 mJy at 2GHz
($Jy = 10^{-26}\ W \cdot m^{-2} \cdot Hz^{-1}$)

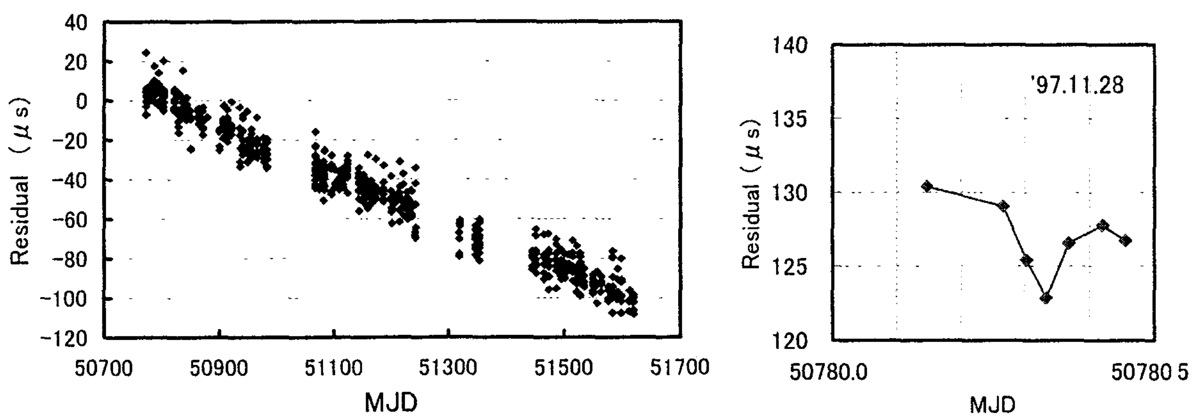
Integration time: 30 min.
Detecting bandwidth: 50 MHz

Figure 2: Pulse profile of MSP1937+21. Integration time is 27 minutes and observation bandwidth is 50MHz



(a) (b)

Figure 3: Timing residuals after the first analysis. Each residual is obtained from the peak phase of the pulse after the 27-minute integration. (a) Full data from Nov. '97 to Mar. '00. The windings are due to the insufficient calibration of observation time and frequency. (b) One day's example. The drift is due to the insufficient calibration of earth rotation parameter.



(a) (b)

Figure 4: Timing residuals after fixing the problems. (a) Full data. (b) One day's example.

Table 1: Comparison of parameters obtained for PSR1937+21

	Kaspi, APJ,428,'94 Arecibo 305m antenna	CRL ('97nov.-'00Mar.) Kashima 34m antenna
RA	19h 39m 38s.560210	19h 39m38s.560300 (±0.0002)
Dec	21°34'59".14166	21°34' 59".14042 (±0.005)
Parallax (mas)	0.12	1.32 (±1.8)
Pmotion(RA)(mas/yr)	-0.130	-0.284 (±0.3)
Pmotion(Dec) (mas/yr)	-0.464	-0.378 (±0.5)
Frequency (Hz)	641.9282626022265	641.9282626019291 ($\pm 3e^{-10}$)
dF/dt (s^{-2})	$-4.331671 \times 10^{-14}$	$-4.331327 \times 10^{-14}$ ($\pm 9e^{-19}$)

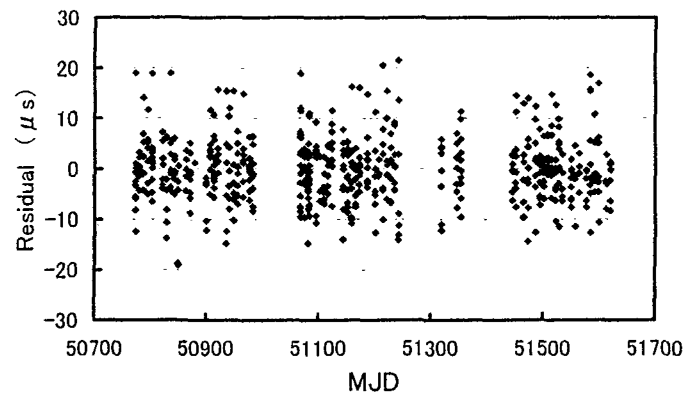
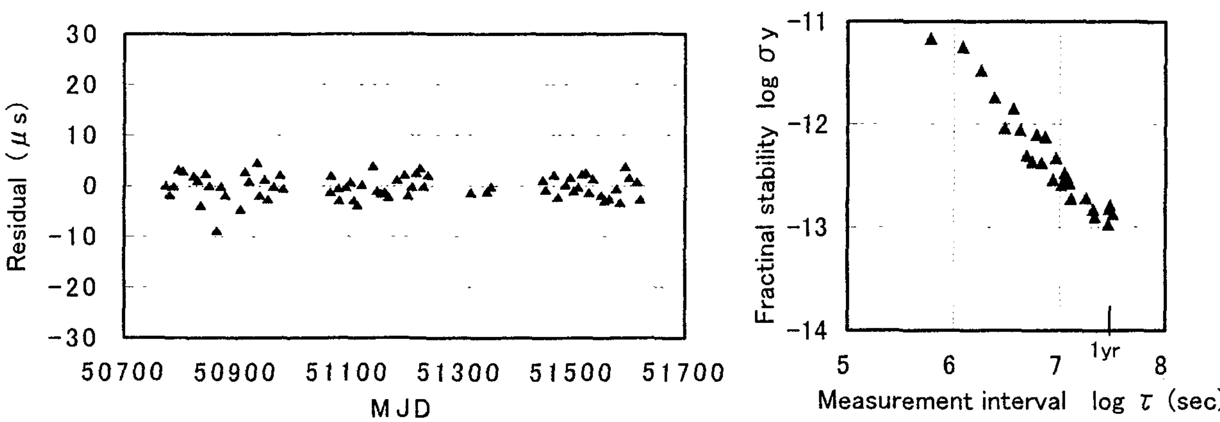


Figure 5: Timing residuals after the parameter fitting. Standard deviation is 6.4 μs.



(a) (b)

Figure 6. (a) Timing residuals for one day's averaging. Standard deviation is 2.4 μs
(b) Allan variance.